

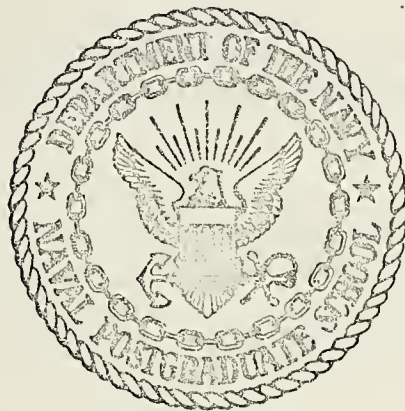
AUDITING ANALYSES OF  
TECHNOLOGICAL CHANGE

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# NAVAL POSTGRADUATE SCHOOL

Monterey, California



## THESIS

AUDITING ANALYSES OF  
TECHNOLOGICAL CHANGE

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*Approved for public release; distribution unlimited.*

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Auditing Analyses of

Technological Change

by

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## ABSTRACT

The objective of this study was to investigate a proposed method of auditing cost-effectiveness analyses of technological changes. The method is based on the use of cost functions to predict costs of operating with and without the improved technology. A comparison of these predicted costs indicates whether the technological change is cost-effective. Results of the comparison can then be used to audit more detailed analyses of the change. The investigation employed econometric techniques in a case study application of the method to a technological change which occurred at the Naval Air Rework Facility, North Island, San Diego, California.





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## I. INTRODUCTION

### A. DEFINITION OF THE PROBLEM

It is commonly accepted that technological advancements are arriving at a faster and faster pace with the state of the art generally far ahead of the functional application. One reason for this gap is the costly enterprise of transferring theory into practice. When the initial transfer is made a natural question to ask prior to extensive implementation is "Will it be cost-effective?" Current methods of cost-effectiveness analysis are tedious and usually employ a detailed analysis of the process which incorporated the change. Such analyses are inherently imprecise due to the possibilities of overlooked dependencies, double counting of costs, and external changes which may affect the effectiveness of the process and yet not be accounted for in the analysis. Thus when a cost-effectiveness analysis is completed a reviewing agency might well ask, "Are the conclusions of the analysis correct?" As mentioned, the methods employed in the analysis make this second question a hard one to answer.

This study is solely concerned with investigating a method which may simplify the task of answering the second question; that is, a method for auditing cost-effectiveness



analyses of technological changes. The investigation was accomplished by applying the method to a specific technological change which occurred at the Naval Air Rework Facility at North Island, California (NARFNI). While an indirect product of this study is a statement concerning the cost-effectiveness of the change which occurred at NARFNI, it is emphasized that the purpose of the study is to investigate and refine an auditing method initially proposed by Robert L. Spooner [Ref. 4], which was based on the estimation of production functions through linear least-squares regression techniques. A description of Spooner's proposal and later refinements established by Charles W. Bradley [Ref. 1] and Wilber C. Trafton [Ref. 6] will be given in Chapter II.

## B. NARFNI

NARFNI is one of seven naval air rework facilities throughout the continental United States responsible for major maintenance, conversion and repair of United States Navy and Marine Corps aircraft and related components. To accomplish this mission NARFNI employs approximately 6800 civilian workers and spends \$150 million on annual operating expenses [Bradley, pp. 8 and 12].

Maintenance of equipment is accomplished under one of three primary programs, with two of the programs receiving inputs either directly from the customer or from the third program (see Fig. 1).



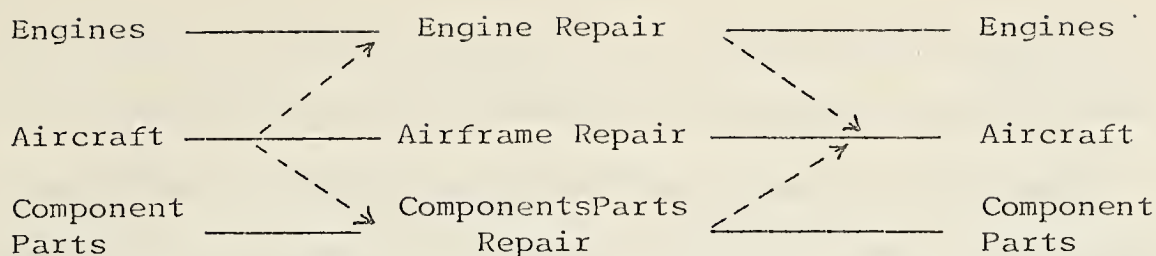


FIGURE 1. NARFNI Repair Programs

Under these programs work is further assigned to one of the six divisions of the Production Department identified in Figure 2.

Weapons #1  
 Weapons #2  
 Hydraulic/Mechanical  
 Power Plant  
 Avionics  
 Components and Metal

FIGURE 2. Production Department Divisions

The assignment of work to various programs and production divisions can be thought of as a "job shop" operation in which each shop performs a specific task. Thus an item entering rework is subject to being dismantled, its sub-assemblies distributed for rework, and then reassembled prior to returning to the customer. This type of operation places emphasis on the scheduling of rework in that ideally the shops are completing work on related parts in the same sequence to reduce the total repair time of the major end items.



Scheduling is also important to the shop managers who must order material and plan personnel assignments based on the projected arrival of work from other shops. This entire scheduling problem is intimately related to the technological change to be described in the following section.

NARFNI is primarily funded by the Navy Industrial Fund (NIF) which provides a working capital fund to finance repair operations. The finished product is returned with a bill to the customer for the work done. This "debt" is then paid by transferring funds from the customer's appropriated maintenance funds to the NARF's working capital fund. Under this concept NARFNI is required to control its finances to incur zero profit at the end of each fiscal year. This control is exercised at Quarterly Planning Conferences in which representatives from the customers and NARFNI meet to plan the following quarter's work load input and prices for the work to be accomplished.

The work load is measured in number of required man hours (NORM) of direct labor needed to accomplish the work requested by the customers. The NORM is estimated from historical data maintained by NARFNI on each type of work it has accomplished in the past.

NARFNI is reimbursed under basically two types of contracts, cost reimbursable and fixed price, the majority of





the work being performed under fixed price contracts established at the Quarterly Planning Conference. This type of contract gives NARFNI incentive to minimize costs subject to the required work load, a fact which is instrumental to the auditing method investigated.

#### C. WORK IN PROCESS INVENTORY CONTROL SYSTEM (WIPICS)

In January, 1972, NARFNI installed an industrial information system to assist in the location and scheduling of inventory in the rework process. WIPICS was requested and initiated by the Management Systems Development Office (MSDO) in an effort to assist the NARF's in performing their mission at a minimum cost to the government. If the prototype at NARFNI is determined to be cost-effective WIPICS will then be installed at the remaining six NARF's. Its major milestones are listed in Figure 3.

1. Early 1969 - ROHR Corporation studied NARFNI
2. Late 1969 - MSDO requested contract
3. Early 1970 - NAVAIRSYSCOM evaluation and approval
4. July 1970 - SECNAV authority for prototype
5. Late 1970 - Contract negotiated
6. 4 January 1971 - Contract date, D-Day
7. D + 9.5 months - WIPICS developed
8. D + 11 months - WIPICS test
9. D + 11.5 months - WIPICS prototype started

FIGURE 3. WIPICS Milestones



WIPICS consists of a central computer which is linked to the job shops by 164 "touch tone" telephones, 20 alphanumeric terminals, and four teletypewriters. In addition, the system is equipped with an 80 word audio-response unit to allow two-way communication through the telephones. When an item first arrives at NARFNI it is broken down into identifiable subassemblies. For each of these subassemblies a computer record is created and entered into WIPICS. This record contains information such as identification, required work, required material, location, and status. Each job shop inputs arrival and departure information through the "touch-tone" telephones. Also, an unexpected delay in work due to lack of material or some other shortcoming is inputted as it occurs. At the completion of the work day a print-out of this information is produced to aid shop managers in projecting the rate and mix of work that will be entering their respective shops in the near future.

The inauguration of the WIPICS prototype was accomplished by creating computer records for all jobs presently in the shop to preclude a lengthy start up before evaluation could begin. Simultaneously, the operational costs accountable to WIPICS were transferred as overhead to be applied to the price of jobs in shop. Thus, during January, 1972, NARFNI initiated a technological change which was to be subjected to



cost-effectiveness analysis and, at the same time, provided a suitable situation to use in investigating a method for auditing cost-effectiveness analyses.

#### D. SCOPE OF STUDY

Previous work conducted by Spooner, Bradley, and Trafton was directed at completing a methodology for determining if NARFNI is operating more efficiently after installation of the WIPICS prototype. However, the method is relatively new itself and numerous problems prevented completion of the effort. One major problem was the lack of production data after the incorporation of WIPICS. The purpose of this study is to complete that work. The remaining portions of the study are divided into the following categories:

1. Discussion of the methodology and production data available from NARFNI.
2. Preliminary estimation of NARF costs as functions of the work load and prices of inputs, and analysis of the characteristics of these functions.
3. Estimation and analysis of before and after WIPICS cost functions followed by a direct comparison of the two cost situations.
4. Discussion of the exogeneous variables which were not included in the estimation of the cost functions.
5. Conclusions.



## II. METHODOLOGY AND DATA

### A. GENERAL

The instructional objective is to determine the effectiveness of WIPICS. The major difficulty in attaining this objective is the probable abundance of other changes which make the before and after WIPICS situations different. Thus, a direct comparison of costs is invalid. The ideal solution would be to operate two "identical" NARF's, one with and one without WIPICS, and then compare costs. While this solution is unobtainable an estimation of its outcome is not. The costs of those two NARFs can be estimated through the use of econometric techniques to construct before and after WIPICS cost functions. The estimation methods were reported by Trafton but are outlined in Sections B, C, and D for reference.

In order to estimate the cost functions their structure must first be specified by solving a mathematical program in which NARFNI is assumed to be minimizing costs subject to a production function,

$$\begin{aligned} \text{minimize} \quad C &= P_1 X_1 + \dots + P_n X_n \\ \text{subject to} \quad Y &= F(X_1, \dots, X_n). \end{aligned} \tag{1}$$

As stated in Chapter I, NARFNI has three major programs, each producing many different outputs. For example, the airframe program produces airframe repairs on 20 quite





different aircraft, and the engine program has an even more varied output. To obtain a more tractable situation the problem at (1) was solved and then applied to the major NARFNI programs separately. The result is one cost function for the airframe program and one for the engine program. Before describing the form of the cost functions a description of the data available and the types of production functions assumed to hold is necessary.

#### B. NARFNI PRODUCTION DATA

The data was obtained from NARFNI's Production Performance Report, a quarterly report which details the total resources expended on each airframe and engine which has completed its repair process. The report does not include detailed information on the component parts program but rather a monthly summary of total resources expended in that program. A description of the data for airframes and engines is given below.

1. Identification - includes the type of aircraft or engine and the extent of work required, such as overhaul, repair of crash damage, modification, or conversion. The type of work required affects the NORM assigned to the item.
2. NORM - is NARFNI's estimate of the direct labor hours required to accomplish the work. NORM is established



at the Quarterly Planning Conference before induction of the item.

3. Induction and completion date - are the Julian dates the item actually entered rework and then work completed.
4. Direct labor hours (L) - is the total labor hours that can be specifically identified with rework of the item.
5. Direct labor dollars (L\$) - is the total cost of the direct labor expended on the item.
6. Material dollars (M\$) - is the total cost of materials that can be specifically identified with rework of the item.
7. Overhead dollars (O\$) - is a prorated portion of those NARFNI costs which cannot be identified with specific items in rework.

The data taken from the Production Performance Reports are raw in the sense that they represent actual costs per item. Bradley wrote a computer program which prorates the NORM, DLH, DL\$, M, O for each item over the number of days the item was in shop. The program then aggregates the prorated data to obtain daily totals for the engine and airframe programs for the period under study. Bradley's program generates one additional variable, the number of items in rework (I) on each day. Trafton modified these programs



to include a penalty cost ( $P\$$ ) chargeable to each item for every day it was in the NARF [6, p. 22]. This was an effort to reflect pipeline costs which may be the costs most significantly altered by WIPICS. These penalty costs are especially significant in the component parts program. A relatively small part, such as a generator, may be the prime reason an F-4 aircraft is non-operational at its home base. Unfortunately, lack of data in the component parts program prevented inclusion of that program in this thesis.

Two variables were constructed from the aggregated data.

$PL = \frac{L\$}{L}$ , which is a rough surrogate for the price of labor, and

$PI = \frac{P\$}{L}$ , which is an average penalty cost per item on a given day.

Notice that PL will vary with changes in the amount of overtime employed as well as a general pay raise. It may also vary as the distribution of jobs in the work load changes from one level of skill to another.

### C. PRODUCTION FUNCTIONS

Two structures for the production function in the economic problem of Section A were used, the Cobb-Douglas and the Constant Elasticity of Substitution (CES) production functions. This was done to compare the ability of each to model the relationship between NARFNI's inputs and outputs. In each program the output is approximated by NORM produced



each day. This approximation is necessary due to the numerous types of airframes and engines being repaired. Since NORM is measured in the same units for every item it is a simple way of measuring production while at the same time reflecting the amount of work accomplished by NARFNI each day.

The Cobb-Douglas production function was assumed to have three inputs:

1. L with price PL
2. I with price PI
3. M with price 1 (since material is measured in dollars).

Thus the production function takes on the form

$$\ln N = \alpha_0 + \alpha_1 \ln L + \alpha_2 \ln I + \alpha_3 \ln M. \quad (2)$$

The CES production function was assumed to have two inputs, L and I, and takes the form

$$N = \gamma \left[ \delta I^{-\rho} + (1-\delta) L^{-\rho} \right]^{-\frac{\sigma}{\rho}}$$

or  $\ln N = \ln \gamma + \frac{-\sigma}{\rho} \ln \left[ \delta I^{-\rho} + (1-\delta) L^{-\rho} \right] \quad (3)$

The Cobb-Douglas production function was selected for its useful and convenient application in empirical work. It is a special case of the CES function in that the limit of the CES production function, as  $\rho \rightarrow 0$ , is the Cobb-Douglas function. Therefore, the elasticity of substitution ( $\sigma$ ) of inputs is assumed fixed at one in the Cobb-Douglas function and it is only assumed to be a constant in the CES function [2, p. 327].





The CES production function was included in the study specifically because it allows to differ from unity and therefore, should present a more accurate model of NARFNI's production relation should this be the case. This advantage is offset, however, by the fact that the CES function at (3) above is not linear in the parameters and estimation of the resulting cost function becomes more difficult.

#### D. ESTIMATING THE COST FUNCTIONS

The following procedures apply to both the airframe and engine cost function estimation. For this reason only the airframe procedures are presented.

##### 1. Cobb-Douglas Cost Function

The cost function is derived by solving

$$\min C = PL(L) + M + PI(I)$$

$$\text{st. } N = AL^\alpha I^\beta M^\gamma \quad \text{[see 6, p. 32]}$$

where the dependent variable in the objective function is defined as  $DL\$ + M + P$ . The Lagrangian (LG) is

$$LG = PL(L) + M + PI(I) - \lambda(N - AL^\alpha I^\beta M^\gamma). \quad (4)$$

The 1st order conditions are obtained by taking partial derivatives of (4) with respect to  $L$ ,  $M$ ,  $I$ , and  $\lambda$ . The results are:

$$LG_L = PL + \lambda \alpha AL^{\alpha-1} I^\beta M^\gamma \mu_L \quad (5)$$

$$LG_M = 1 + \lambda \gamma AL^\alpha I^\beta M^{\gamma-1} \mu_M \quad (6)$$

$$LG_I = PI + \lambda \beta AL^\alpha I^{\beta-1} M^\gamma \mu_I \quad (7)$$



$$LG_{\lambda} = N - \alpha L^{\alpha} I^{\beta} Me^{\gamma} \quad (8)$$

where the  $\epsilon$ 's are random variables associated with errors due to imperfect cost minimization by NARFNI.

These 1st order conditions can be solved to obtain the inputs as functions of the prices and output. Substitution of these functions into the logarithmic form of the cost function yields

$$\ln C = a + \frac{1}{\alpha + \beta + \gamma} \ln N + \frac{\alpha}{\alpha + \beta + \gamma} \ln PL + \frac{\beta}{\alpha + \beta + \gamma} \ln PI + \epsilon \quad (9)$$

where the error term ( $\epsilon$ ) is assumed to be normally distributed with mean zero and constant variance.

Standard linear least-squares regression techniques [5, Chap. 3] were used to estimate the coefficients of the variables in (9). The results are reported in Chapters III and IV.

## 2. Constant Elasticity of Substitution Cost Function

Again, the cost function is obtained by solving

$$\begin{aligned} \min C &= PI(I) + PL(L) \\ \text{st } N &= \gamma \left[ \delta L^{-\rho} + (1-\delta) I^{-\rho} \right]^{-\sigma/\rho} \end{aligned}$$

where  $C$  is now defined as  $DL\$ + O + P$ . The resulting function

$$\ln C = \alpha + \ln \left[ PL + PI(I/L) \right] + \beta \ln N + \omega D + \epsilon \quad (10)$$

in which

$$\begin{aligned} \alpha &= -\frac{1}{\sigma} \ln \gamma \\ \beta &= \frac{1}{\sigma} \\ \omega &= \frac{1}{\rho} \\ D &= \ln \left[ (1-\delta) + \delta \left( \frac{I}{L} \right)^{-\rho} \right] \end{aligned} \quad (11)$$



The equation at (10) is not linear in the original parameters of the production function and, therefore, cannot be estimated by the same procedures used on the Cobb-Douglas cost function. A more complex two-stage least-squares regression technique was used instead. The first stage consists of a linear least-squares estimation of

$$\ln (I/L) = a + b \ln (P^I/PL) + \epsilon \quad (12)$$

where

$$a = \left(\frac{1-\delta}{\delta}\right)^{-\frac{1}{\rho-1}} \quad \text{and} \quad b = -\frac{1}{\rho-1}.$$

Equation (12) is derived from the first order conditions of the mathematical program [see Trafton, p. 18]. The resulting estimate of  $(I/L)$  is then substituted into D at (11). The estimate of D is then substituted into (10) which becomes linear in the parameters. Thus, the second stage consists of a linear least-squares regression to estimate the coefficients of (10).

A comparison of the Cobb-Douglas and CES cost functions derived is discussed in Chapter III where a preliminary analysis of the procedure is reported prior to application of the entire auditing methodology.



## E. DIRECT COMPARISON OF THE COST FUNCTIONS

To estimate the effect of WIPICS on NARFNI's efficiency the cost functions derived in Section D were estimated using aggregated production data from a period of time prior to the inauguration of WIPICS to obtain before-WIPICS engine and airframe cost functions. The procedure was then repeated using aggregated production data for a period after WIPICS for an after-WIPICS cost function for each program (Fig. 4).

	Before WIPICS	After WIPICS
Airframes	CD cost function CES cost function	CD cost function CES cost function
Engines	CD cost function CES cost function	CD cost function CES cost function

FIGURE 4. Cost Functions Estimated

To compare the two situations the before and after data were consolidated and used in the before and after cost functions to estimate daily program costs for a given period. By averaging the difference between the expected cost with WIPICS and the expected cost without WIPICS a mean cost differential is predicted for each of the following situations:

1. NARFNI operation with and without WIPICS using before WIPICS observations.
2. NARFNI operation with and without WIPICS using after WIPICS observations.





This procedure is followed for both the Cobb-Douglas and CES functions. The computer program constructed for this purpose is listed at Appendix A.

#### F. DATA

Production data was obtained on the engine program for two separate periods. The first period covered 1865 engines inducted on Julian dates 0140 through 1273. The aggregated results obtained from this period is listed in Appendix B of Bradley's thesis. The second period covered 521 engines inducted on 2003 through 3050 with the aggregated results listed at Appendix B of this thesis. Data on the airframe program covered 564 airframes inducted on 0069 through 2234. The aggregated results from Julian date 1001 forward are listed in Appendix C.

The operational cost of WIPICS chargeable to NARFNI averages approximately \$48,000 per month or \$1600 per day. NARFNI was not held accountable for these charges until January, 1973.



### III. PRELIMINARY ANALYSIS

Before attempting to apply the procedures outlined in Chapter II a preliminary analysis was performed to develop methods of characterizing the estimation techniques. This was accomplished by using a 400 day period of data to estimate cost functions and test for stability and accuracy. The resulting procedures were then included in the final analysis of the technological change. The 400 day period used in this chapter was well before the WIPICS prototype became operational. Therefore, the results obtained should reveal some of the problems to look for in the estimation of the cost functions, that is, the expected variability of the cost function due to events other than the implementation of WIPICS.

#### A. REGRESSION RESULTS

Using the procedures outlined in Chapter II Cobb-Douglas and CES cost functions were estimated from 300 days of aggregated production data. The resulting coefficients are presented in Table I. The results of the first stage of the estimation procedure for the CES cost function is not presented unless the coefficients are not significantly different from zero.  $R^2$ , when multiplied by 100, is the percentage of total variation in cost that can be explained by the estimated



function. SE is the standard error of the estimated cost function (in logarithmic form), and the number in parenthesis is the standard error of the coefficient just above it. Standard errors for leading coefficients are not computed.

Airframes<sup>1</sup>

Function	Coefficients	SE	R <sup>2</sup>
CD:	.624 .760 2.754 -.267 (.015) (.066) (.036)	.021	.956
CES:	.2175 0.870 -.2.461 (.007) (.182)	.011	.980
CD:	3.046 .877 .401 .032 (.017) (.095) (.052)	.035	.907
CES:	2.506 .851 21.152 (.025) (6.113)	.053	.808

Engines<sup>2</sup>

TABLE I. Before WIPICS Cost Functions (Preliminary)

---

<sup>1</sup> 300 observations from 0191 to 1226.

<sup>2</sup> 300 observations from 0215 to 1150



It should be noted that the dependent variable of the CES second stage regression is not  $\ln C$  but rather

$$\ln \left[ \frac{C}{PL + PI(I/L)} \right].$$

Also, the  $C$  representing costs in the Cobb-Douglas function is the sum of material, penalty, and labor dollars, where as the  $C$  in the CES regression is overhead, penalty, and labor dollars. These two differences may explain why, in the air-frame program, the CES function has a higher  $R^2$  than the Cobb-Douglas (indicating a better fit) while the Cobb-Douglas has a lower standard error (indicating it is more accurate). The two functions are thus not comparable in this form so different methods of comparison were needed.

A rough test for the significance of the coefficients in Table I can be made by taking the ratio of the coefficient to its standard error. If this ratio is less than two the coefficient is not significantly different from zero at approximately the 5% level of significance. All coefficients in Table I are significantly different from zero by this test and the conclusion can be made that each independent variable contributes to the explanation of the dependent variable.





## B. STABILITY OF THE MODELS (CHOW TEST)

With the large fluxuation in work load and type at NARFNI (see NORM and penalty cost values in Appendices B and C) it is probable that the production and cost functions for NARFNI's programs shift considerably even though technology is in fact not changing. Inherent instability such as this may camouflage the shift due to technology and should, therefore, be tested for by means of the Chow Test [3, pp. 104-112].

The Chow Test is founded on the general principle that a regression line will not pass through every data point and that data obtained from two different populations can be better fit with a regression for each population than with a single regression for the total data set. If the converse of the above statement is assumed to hold, then a test to see if two sets of data are from the same population may be obtained by seeing if a single regression fits as well as two separate regressions on the respective data sets. To extend this test to the cost functions a second regression was performed on the 100 day periods following the 300 days in each of the two programs under study. The data was then combined and regressions run on the 400 day periods. The test statistic used was

$$F(k, n_4 - 2k) = \frac{n_4(SE_4) - n_3(SE_3) - n_1(SE_1)}{n_3(SE_3) + n_1(SE_1)} \frac{n_4 - 2k}{2k}$$



The subscripts refer to the respective data periods of 400, 300, and 100 days. SE is the resulting equation's standard error, n is the number of observations, and K is the number of coefficients estimated in each equation. If the test statistic is too large then the hypothesis that the two periods have the same cost function is rejected. Results are presented in Table II.

	Model	Test Statistic	Critical Value	Results
Airframes	CD	12.147	F(4,392) 2.43	Reject
	CES	28.78	F(5,390) 2.27	Reject
Engines	CD	14.741	F(4,392) 2.43	Reject
	CES	41.22	F(5,390) 2.27	Reject

TABLE II. Chow Test Results (Preliminary)

The entire 400 day periods used in the Chow Test fell well before WIPICS was operational at NARFNI indicating the cost functions are not stable, even with fixed technology. This revealed a possible problem in applying the auditing methodology proposed by Spooner. However, it may be possible to diminish the importance of the instability if it is not too great. This can be done by increasing the sample size to well over 400 days, thereby allowing the variations in work



load to average out. This technique would prove ineffective against large, prolonged projects of a particular work type such as major modification of all F-4 aircraft in the Navy's inventory. In addition, this solution would mean waiting, perhaps for years, before obtaining enough data, after the technological change, to conduct the analysis. In most cases the requirement for the study would have long since been dropped.

A more generally acceptable solution would be to accept the cost function for use as long as it can accurately predict costs while at the same time keeping the accuracy in mind when final conclusions are drawn. This acceptance can only be justified if the accuracies of the function are measured.

## C. ACCURACY OF THE COST FUNCTIONS

### 1. Empirical Confidence Intervals

If  $e_i$  is the error of the predicted cost for the  $i^{th}$  observation a confidence interval can be empirically constructed by using the ratio of two standard errors<sup>3</sup> of the function over the actual mean costs for the period. The result is a percent error in cost,

---

<sup>3</sup> The term "standard error" is miss-used here since nothing is known about the distribution of the error terms. Still, the procedure is not uncommon.



$$\% \text{ error} = \frac{2 \sqrt{\sum e_i^2 / n}}{\sum C_i / n} \times 100.$$

The % error approximates  $\pm 2$  standard deviations which accounts for about 90% of the mass in most probability distributions. Thus, there is approximately a 90% confidence that the predicted cost is within the percent error computed of the actual cost.

This procedure was performed on the cost functions estimated from the 300 day period, and then on the 100 day period with costs being predicted by the 300 day models (Table III).

	Model	300 Observations	100 Observations
Airframes	CD	$\pm 04.0\%$	$\pm 05.0\%$
	CES	$\pm 02.3\%$	$\pm 03.1\%$
Engines	CD	$\pm 07.0\%$	$\pm 15.7\%$
	CES	$\pm 11.1\%$	$\pm 14.6\%$

TABLE III. % Errors in Cost Functions (Preliminary)

As the standard errors seemed to indicate in Table I, the CES cost function appears better for the airframe program while the results are mixed for the engine program. The largest errors are in the engine program when the functions were used to predict costs. This is understandable since the engine work load and mix of work fluctuate more rapidly and extremely than those of the airframe program. The results also indicate that the engine cost functions may be





highly sensitive to small shifts in the data period used. Finally, in the 300 day functions for engines, the Cobb-Douglas model appears to do a better job than the CES. This is counter to expected results and is not explained.

## 2. Statistical Prediction Intervals

A similar procedure to that of subsection 1 uses statistical methods outlined in Theil [pp. 134-135] to construct prediction intervals. Let  $C'$  represent the estimated cost and accept the assumptions of the standard linear model [5, pp. 110-111]. Then the following probability statement holds:

$$P(\ln C'_1 - H \leq \ln C_i \leq \ln C_i + H) = 1 - \alpha$$

where

$$H = t_{\alpha/2} (SE) \sqrt{1 + V'_0 (X'X)^{-1} V_0}$$

$X$  = matrix of independent variables used to construct the model

$V_0$  = vector of independent variables used to predict  $\ln C_i$

$t_{\alpha/2}$  =  $t$ -statistic

This interval is in logarithms. The transformed interval in costs becomes non-symmetric and non-linear in the independent variable of  $V_0$ . Thus, it is more accurate to compare the extreme widths of the intervals than the mean values compared in subsection 1.



Prediction intervals were computed for the 100 day period using the 300 day models of Table I. Of the 100 prediction intervals resulting the minimum and maximum interval were transformed to dollars and then divided by the mean cost for the 100 day period to obtain a maximum and minimum width as a percentage of the average cost (parenthetical entries of Table IV). Finally, the percentage of actual costs that fell outside their corresponding prediction interval is reported in the last column of Table IV. Computer programs written to perform these computations are reproduced at Appendices D and E.

	Model	Max. Interval	Min. Interval	% Out- side Interval
Airframes	CD	6729 (8.5%)	5365 (6.8%)	4%
	CES	4480 (4.0)	3347 (3.0)	32%
Engines	CD	5375 (12.5)	3783 (8.8)	62%
	CES	6943 (20.5)	4836 (14.3)	29%

TABLE IV. Extreme Widths of 90% Prediction Intervals (in dollars)

### 3. Accuracy of the Measures

Table III and IV should be roughly comparable by doubling the % error under the 300 observations column of Table III. This value should fall between the maximum and minimum percentage values for the same function in Table IV.



As can be seen, the statistical values of Table IV tend to be smaller when this comparison is made. Moreover, a larger discrepancy between the two tables is accompanied by a larger percentage of the actual costs falling outside of the prediction interval of Table IV.

Some of this difference may be accounted for as interpolation errors for the  $t$ -statistic used in the equation at (7) to obtain Table IV. Errors in this statistic are exponential in nature and the resulting prediction intervals were found to be quite sensitive to the value used. The same

$t$ -statistic value was used for all of the functions in Table IV which seems to imply the value chosen was low. A slight increase in this value would increase the prediction intervals, make Table IV more consistent with Table III, and should, at the same time, decrease the percentage of actual costs falling outside the corresponding prediction interval. More care was taken in selecting this value in Chapter IV where the auditing methodology is carried through completely.

Finally, the uneven prediction results between the cost functions of Table IV may be indicative of the Chow Test's conclusion that the two periods of data, 300 vs. the following 100 days, are in fact different and a model of one period is a poor prediction of costs in another period. This



possibility is important because the periods are not separated by a recognizable technological change. It reemphasizes the need to include the accuracy of the models in the final comparison of estimated costs.





#### IV. COMPARISON OF BEFORE AND AFTER

##### WIPICS PREDICTED COSTS

###### A. THE COST FUNCTIONS

The final cost functions used to compare estimated costs across the technological change were obtained using the SNAP/IEDA Computing Package developed by the Department of Statistics, Princeton University. SNAP/IEDA will accept up to 400 observations. In those models requiring over 400 observations the BIMED-02R program, developed by the Health Sciences Computing Facility, University of California, was used for the Cobb-Douglas estimation. The CES estimation was limited to 400 observations in all cases since estimation using the BIMED-02R program would become a 3 stage procedure requiring excessive manipulation and inefficient use of computer time. Also, for the final cost functions, the data periods were altered for two reasons. First, the data periods were chosen close to the technological change so the before and after situations would be as similar as possible, except in technology. Second, the data periods were altered in size and content to reduce the effects of instability as much as possible. The results are presented in Tables V and VI with footnotes indicating the data used.



Note that the CES function for engines across WIPICS was not estimated due to the large number of observations involved. Omission of this function merely precludes performing a Chow test which in all probability would be rejected if performed. Visual comparison of the before and after functions supports this.

		Function Coefficients				SE	R <sup>2</sup>
Before <sup>4</sup> WIPICS	CD	-.297	.857 (.011)	2.356 (.090)	-.094 (.015)	.014	.949
	CES	2.999	.886 (.019)	-10.421 (.543)		.025	.852
After <sup>5</sup> WIPICS	CD	-1.213	.745 (.071)	4.222 (1.234)	-.487 (.066)	.017	.876
	CES	2.098	.881 (.016)	-2.724 (.293)		.006	.980
Across <sup>6</sup> WIPICS	CD	2.934	.884 (.017)	.674 (.035)	-.179 (.023)	.020	.893
	CES	1.945	.907 (.025)	-3.424 (.578)		.031	.778

TABLE V. Airframe Cost Functions

<sup>4</sup> 400 observations from 0316 to 1350.

<sup>5</sup> 90 observations from 2090 to 2179.

<sup>6</sup> Periods 1 and 2 above except dates ending in 3, 5, or 7 deleted to reduce the number of observations to 343. This technique was applied to the before and after case with essentially the same coefficients resulting as reported above. Thus, deletion of some data should not have significantly affected the across WIPICS coefficients.



Function		Coefficients				SE	R <sup>2</sup>
Before WIPICS	CD <sup>7</sup>	2.104	.837 (.018)	.147* (.111)	.494 (.058)	.051	.819
	CES <sup>8</sup>	1.357	.897 (.026)	-.135* (.422)		.059	.755
After <sup>9</sup> WIPICS	CD	4.021	.708 (.020)	-.750 (.163)	.715 (.080)	.029	.922
	CES	-134.11	.477 (.016)	-.812 (.327)		.035	.861
Across <sup>10</sup> WIPICS	CD	3.408	.729 (.013)	.345 (.043)	.271 (.036)	.050	.854
	CES	not estimated					

TABLE VI. Engine Cost Functions

\* Not significant at the 5% level.

---

<sup>7</sup> 463 observations from 0184 to 1281.

<sup>8</sup> 400 observations from 0215 to 1250.

<sup>9</sup> 160 observations from 2158 to 2317.

<sup>10</sup> 623 observations for the CD Model.



All coefficients for the airframe functions are significantly different from zero. In addition to the two starred coefficients which were not significant in the engine functions, the coefficient of  $\ln(I/L)$  in the first stage of the before WIPICS CES estimation was not significant. Since the functions were estimated from varying time periods the SE and  $R^2$  are representative of only the respective function and should not be compared across functions. Thus, to characterize the functions the Chow Test and statistical prediction interval discussed in Chapter III were used.

#### B. STABILITY ACROSS THE CHANGE

The Chow Test was used on the cost functions to determine if they were in fact different before and after WIPICS (Table VII).

	Model	Test Statistic	Critical Value	Results
Airframes	CD	16.94	(4.362) 2.43	Reject
	CES	23.98	(4,362) 2.43	Reject
Engines	CD	8.30	(4,615) 2.43	Reject
	CES	(Not computed)		

TABLE VII. Chow Test Results





In all tests the hypothesis that the before and after WIPICS's cost functions are the same was soundly rejected. This implies the additional conclusion that a technological change "may" have affected the relationship between inputs and outputs.

### C. PREDICTION INTERVALS

90% prediction intervals were calculated for the before and after WIPICS's functions by using the functions to predict costs for the last 100 days (90 days for after WIPICS airframe functions) of this respective time periods. The same procedure used to construct Table IV was then used to construct Table VIII.

The most striking result is the improvement obtained in percent of observations falling outside the prediction interval. This occurred because the 100 costs predicted were in fact a subset of the sample used to construct the cost functions. A second difference from Table IV is the size of the prediction intervals. The change was mixed, some larger and some smaller. This again points to the relatively unstable situation at NARFNI in which prices and amounts of inputs appear to be varying widely.

Although the prediction intervals are non-symmetric about the predicted cost, one half of the maximum interval should safely represent at least two standard errors of the cost



	Model	Maximum Interval		Minimum Interval		% Outside Interval
Before WIPICS	Airframes					
	CD	4122 (4.9%)	3461 (4.1%)	14.0%		
	CES	10760 (9.0%)	8740 (7.3%)	11.0%		
	Engines					
	CD	8287 (20.6%)	4057 (10.1%)	7.0%		
	CES	7788 (23.1%)	5319 (15.7%)	25%		
After WIPICS	Airframes					
	CD	5429 (6.3%)	4698 5.5%	13.0%		
	CES	2700 (2.2%)	2270 (1.9%)	6.0%		
	Engines					
	CD	4113 (11.3%)	2818 (7.7%)	10%		
	CES	4041 (13.1%)	2943 (9.6%)	21%		

TABLE VIII. Extreme Widths of 90% Prediction Intervals (in dollars)



function. This value will be used to make a significance statement about the cost comparison of operating with and without WIPICS.

#### D. DIRECT COMPARISON OF PREDICTED COSTS

Following the comparison procedures discussed in Section E, Chapter II, the cost differentials in Tables IX and X were obtained.

	CD (BW-AW)	CES (BW-AW)
Before WIPICS Data	\$17885	\$3306
After WIPICS Data	\$9241	\$7129

TABLE IX. Difference Between Predicted  
Costs<sup>11</sup> - Airframes

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<sup>11</sup> Positive value indicates operation with WIPICS is estimated to be cheaper.



	CD (AW-AW)	CES (AW-AW)
Before WIPICS Data	\$5126	\$5286
After WIPICS Data	\$1152	\$3893

TABLE X. Difference Between Predicted  
Costs<sup>12</sup> - Engines

Table IX is read as saying, "Based on the before and after WIPICS Cobb-Douglas cost functions it is estimated that WIPICS could have saved NARFNI \$17,885 per day in the airframe program during the period 0316 to 1350, had WIPICS been in operation at that time." Notice that this says nothing about changes which these cost functions cannot measure, such as an arbitrary change in the NORMS assigned to in coming repair items. These factors will be considered in Chapter V. In addition, the statement does not consider the inaccuracies of the models which were measured in Table VIII. It should be qualified by the assumption that the difference is not significant unless it exceeds, in absolute value, the sum of one-half of the two maximum prediction

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<sup>12</sup> Positive value indicates operation with WIPICS is estimated to be cheaper.





intervals of the cost functions involved. In the above example this sum is \$4776 (computed from Table VIII). Thus, the statement is significant with at least 90% confidence (again, disregarding externalities to be discussed in Chapter V).

Using the above procedure to interpret Tables IX and X the CD models indicate a significant advantage in the air-frame program and an insignificant disadvantage in the engine program. The CES models indicate an insignificant WIPICS advantage in both programs.

The above comparison could be refined by removing the effects of externalities. This should reduce the total variance of costs and it should reduce the maximum prediction intervals of the cost functions. The net result would then be a smaller region in which the cost differential would be considered insignificant, but also possibly smaller indicated cost savings.



## V. VARIABLES EXOGENEOUS TO WIPICS

The Cobb-Douglas and CES models do an imperfect job of estimating the effect of WIPICS on production costs due to many changes within the periods which were not caused by WIPICS. If the major changes were isolated, and the data corrected to account for them, then the procedures discussed in this thesis should give an acceptable estimation of WIPICS' effect. Some of these changes are noted below.

### A. PRICE CHANGES

Looking at the minimization problem of Chapter II, an increase in the price of an input would result in higher costs to produce a given level of output. Alternatively, a cost function estimated from data with low prices would tend to underestimate the cost of production for data taken when prices are high. For this reason increasing prices would depreciate the apparent effect of a technological change. The price of direct labor and penalty costs are accounted for in the cost functions used for this study so their fluctuations should not affect the final comparison of predicted costs. This is not the case for material prices and the prices of indirect labor absorbed into overhead. Shifts in these latter prices could, and should, be corrected by the application of a price index.



## B. COMMAND POLICY CHANGES

This area is often elusive and difficult to identify with specific actions. However, obvious changes, such as a new ceiling on allowable overtime, should be accounted for. An increase in overtime, if not a result of command policy changes, may be caused by temporary inefficiency and shop congestion due to the learning process that often follows a technological change. In this case the correction would consist of identifying the period affected and deleting it from the study.

Another example is a shift in the standards for assigning NORMS at NARFNI. The shift is acceptable if experience shows that required labor hours have actually changed. Any other reason for the shift would result in an imaginary shift in the production function with a concurrent change in the derived cost function. This type of bias could also be corrected by application of an index to the data before estimating the cost functions.

## C. PERSONNEL TURNOVER

A season of large personnel cuts followed by hiring of new personnel would naturally establish a training period in NARFNI. During this period the relative efficiency of workers would be low and a corresponding change in the cost function would be noted. If the training occurred during a



period used to estimate a cost function the function would inherit a bias resulting in comparison errors. The effect is complex, however, it may be that wages paid to personnel are low enough, relatively speaking, to allow the cost of production at a given level to remain approximately constant. Still, the relation between the inputs would be altered and a detailed study would be required to correct for the bias.

#### D. CHANGES IN TYPE OF WORK REQUIRED

In Chapter I it was explained that NARFNI has many different outputs in the form of repairs to various types of airframes and engines. These numerous outputs were aggregated into only two products, repairs of airframes and engines. The cost functions associated with these two products should do an acceptable job of predicting costs so long as the mix of work remains fairly constant within the respective programs. A shift in work type cannot be accounted for by the cost functions. Unfortunately, there is strong evidence that the work loads are shifting considerably. An approach to accounting for these shifts is discussed in Section C of Chapter VI, PROBLEMS OF FURTHER RESEARCH.





## VI. CONCLUSIONS AND PROBLEMS OF FURTHER RESEARCH

### A. EFFECTIVENESS OF WIPICS

The comparison of estimated costs for the "with" and "without" WIPICS situations indicated a savings in the airframe program and a loss in the engine program. The results of the two program comparisons are not additive due to the difference in time periods considered in each program. In addition, the component parts program was excluded from the study because of data format. For these reasons, an overall conclusion concerning the cost-effectiveness of WIPICS could not be extracted from this study.

Upon completion of the study it was found that WIPICS had not been fully operational in the engine and airframe programs for the periods originally stated. Numerous problems in implementing the system prevented a complete test of the system during this period. WIPICS has been completely operational in the airframe program since October of 1972 but was not operational in the engine program as of 4 May, 1973.

The indication of significant savings in the airframe program may be explained by shifts in the external variables discussed in Chapter V, a prime suspect being changes in the types of work.



## B. AUDITING METHODOLOGY

Investigation of the auditing methodology originally proposed by Spooner revealed eight primary steps that are essential to arriving at a strong conclusion:

1. Identify external variations such as command policies and inflation of prices so they may be accounted for in the data.
2. Correct the data for the variations identified in 1 above so the situations before and after the technological change will be as similar as possible.
3. Aggregate the data.
4. Select the periods to study, keeping in mind that closeness to the change will aid in stabilizing functions while, at the same time, a delay may be needed to allow the technological change to become noticeable.
5. Estimate the cost functions.
6. Estimate the accuracy of the functions.
7. Compare estimated costs derived from the cost functions.
8. Draw conclusions from 6 and 7 above.

The audit conclusions may be more meaningful if identical time periods are used in each program studied (assuming there is more than one). This will allow the separate effects to be additive for an overall statement about the effectiveness of the change.



Both the Cobb-Douglas and CES cost functions appeared to vary in ability to represent the production relation of inputs to outputs. Neither function dominated the other in accuracy therefore no conclusion can be made as to which should be used. If only one is to be used the natural choice is the simpler Cobb-Douglas function.

The results of the WIPICS test case indicate there remain problems with the accuracy of the tests. It is believed that relatively simple treatment of the data for external influences would improve this accuracy.

#### C. PROBLEMS OF FURTHER RESEARCH

There are three primary areas in the auditing of cost-effectiveness analyses undergoing current research at the Naval Postgraduate School.

First, Professor James Hartman is applying search techniques in an attempt to improve the estimation of the parameters in the CES cost functions. The 2-stage least-squares regression used in this thesis results in two estimates of the elasticity of substitution in the production function, both of which are significant. The problem is that the two estimates are invariably quite different. It is hoped that better estimates of this parameter will result in a more accurate CES cost function for use in the auditing methodology.



Second, Professor Norman K. Womer is investigating methods of accounting for the shifting of work type in the various programs which is believed to be responsible for much of the inaccuracies in the models used in this thesis. The principal effort in this area is toward developing a computer program to perform the regressions on raw data instead of the aggregated data. Dummy variables are being employed, one for each type of airframe or engine, to account for shifting work type. This requires a number of variables exceeding the capabilities of the computer soft-ware presently available.

Finally, Captain Richard McGarrahan, USA, is investigating a second auditing methodology proposed by Spooner which employs a linear input-output production function instead of the continuous production functions assumed in this thesis. The objective of the work is to establish a basis by which to judge the abilities of the continuous models. The input-output model is expected to be more accurate in that it treats each type of work independently and should therefore be more stable. If the continuous models compare favorably in accuracy they would then be considered more desirable for their ease in handling.





# APPENDIX A

## COST COMPARISON PROGRAM

```

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C COST COMPARISON OF BW VS. AW
C (C-D MODEL FOR ENGINES)
C (CES MODEL FOR ENGINES)
C
C ( FOR AIRFRAME COSTS CHANGE READ FORMAT )
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C DIMENSION D(600,7),X(600,3),TIME(600),ACOST(600)
C
C INITIALIZE SWITCH FOR CES COMPARISON AFTER THE CD COMPARISON
C
C ISIG=0
C
C INITIALIZE PARAMETERS FOR CD RUN
C NUM=# OF OBSERVATIONS
C NUM1=# OF OBSERVATIONS BEFORE THE CHANGE
C NUM2=# OF OBSERVATIONS AFTER THE CHANGE
C
C NUM=467
C NUM1=400
C NUM2=67
C BA=2.104
C BB1=.837
C BB2=.147
C BB3=.494
C AA=15.437
C AB1=.622
C AB2=-.248
C AB3=-2.514
C
C INPUT DATA AND COMPUTE ACTUAL TOTAL COST
C
C DC 10 I=1,NUM
C READ(5,900) (D(I,J),J=1,7)
C ACOST(I)=D(I,3)+D(I,4)+D(I,5)+D(I,6)
C CCNTINUE
C 10
C 900 FORMAT(9X,F7.2,1X,F7.2,1X,F8.2,1X,F8.2,1X,F7.2,1X,F4.0)
C

```



NORM DLH DL\$ M\$ OVHD\$ P\$ NI

INITIALIZE LOCATION FOR MEAN MATERIAL AND OVERHEAD COST,  
BEFORE AND AFTER THE CHANGE

```

QMB=0.
QMA=0.
QCB=0.
QCA=0.
DO 12 I=1, NUM1
  QMB=QMB+D(I,4)/NUM1
  QCB=QCB+D(I,5)/NUM1
CONTINUE
12 NUMP=NUM1+1
DO 13 I=NUMP, NUM
  QMA=QMA+D(I,4)/NUM2
  QCA=QCA+D(I,5)/NUM2
CONTINUE
13 WRITE(6,901) QMB, QMA, QOB, QOA
901 FORMAT (' ', //, 'QMB, QMA, QOB, QOA', 4F10.1, //)
DO 20 I=1, NUM
  TIME(I)=1
  X(I,1)=D(I,1)
  X(I,2)=D(I,3)/D(I,2)
  X(I,3)=D(I,6)/D(I,7)
CONTINUE
20

```

PREDICT COSTS AND TAKE DIFFERENCE BETWEEN BEFORE AND AFTER  
MODELS

```

DC 30 I=1, NUM
D(I,1)=EXP(BA)*X(I,1)**BB1*X(I,2)**BB2*X(I,3)**BB3+QOB
D(I,2)=EXP(AA)*X(I,1)**AB1*X(I,2)**AB2*X(I,3)**AB3+QOA
D(I,3)=D(I,1)-D(I,2)
CONTINUE
30 WRITE(6,910) NUM1
35 WFORMAT(' ', COST VS. TIME FOR BW(.) AND AW(+) MODELS USING ', I4, '
910 1 BW OBSERVATIONS.
CALL PLOTP(TIME(I), D(I,1), NUM1, 1)
CALL PLOTP(TIME(I), D(I,2), NUM1, 3)
I=NUM1+1
WRITE(6,911) NUM2
911 2 AW OBSERVATIONS.
CALL PLOTP(TIME(I), D(I,1), NUM2, 1)
CALL PLOTP(TIME(I), D(I,2), NUM2, 3)
DC 40 I=1, NUM

```







```

AA22=.433
AA23=-3.520
DO 70 I=1,NUM
Z=EXP(BA11+BA12*ALOG(X(I,3)/X(I,2)))
C1=EXP(BA11/BA12)+Z*((BA12+1.0)/BA12)
C2=EXP(BA11/BA12)+1.0
C=ALOG(C1/C2)+X(I,2)*Z)*EXP(BA21)*X(I,1)**EA22*EXP(BA23*C)+QMB
D(I,1)=(X(I,2)+AA11+AA12*ALOG(X(I,3)/X(I,2)))
Z=EXP(AA11/AA12)+Z*((AA12+1.0)/AA12)
C1=EXP(AA11/AA12)+1.0
C2=EXP(C1/C2)+X(I,3)*Z)*EXP(AA21)*X(I,1)**AA22*EXP(AA23*C)+QMA
D(I,2)=(X(I,2)+X(I,3)*Z)*EXP(AA21)*X(I,1)**AA22*EXP(AA23*C)+QMA
D(I,3)=D(I,1)-D(I,2)
CONTINUE
GO TO 35
70 STCP
100 END

```





# APPENDIX B

## SUMMARY OF DAILY STATISTICS OF NARF (ENGINE)

DATA FOR JULIAN DATES 2003 TC 3050  
TOTAL NUMBER OF OBSERVATIONS = 523

JUL DATE	NORM	DIR LH	DIR L\$	DIR M\$	CVHDS	P\$	I
1	10.94	11.92	76.02	177.81	93.11	61.64	1.
2	10.94	11.92	76.02	177.81	93.11	61.64	1.
3	10.94	11.92	76.02	177.81	93.11	61.64	1.
4	10.94	11.92	76.02	177.81	93.11	61.64	1.
5	10.94	11.92	76.02	177.81	93.11	61.64	1.
6	10.94	11.92	76.02	177.81	93.11	61.64	1.
7	10.94	11.92	76.02	177.81	93.11	61.64	1.
8	10.94	11.92	76.02	177.81	93.11	61.64	1.
9	10.94	11.92	76.02	177.81	93.11	61.64	1.
10	10.94	11.92	76.02	177.81	93.11	61.64	1.
11	10.94	11.92	76.02	177.81	93.11	61.64	1.
12	10.94	11.92	76.02	177.81	93.11	61.64	1.
13	10.94	11.92	76.02	177.81	93.11	61.64	1.
14	10.94	11.92	76.02	177.81	93.11	61.64	1.
15	10.94	11.92	76.02	177.81	93.11	61.64	1.
16	10.94	11.92	76.02	177.81	93.11	61.64	1.
17	10.94	11.92	76.02	177.81	93.11	61.64	1.
18	10.94	11.92	76.02	177.81	93.11	61.64	1.
19	10.94	11.92	76.02	177.81	93.11	61.64	1.
20	10.94	11.92	76.02	177.81	93.11	61.64	1.
21	10.94	11.92	76.02	177.81	93.11	61.64	1.
22	10.94	11.92	76.02	177.81	93.11	61.64	1.
23	10.94	11.92	76.02	177.81	93.11	61.64	1.
24	10.94	11.92	76.02	177.81	93.11	61.64	1.
25	10.94	11.92	76.02	177.81	93.11	61.64	1.
26	10.94	11.92	76.02	177.81	93.11	61.64	1.
27	10.94	11.92	76.02	177.81	93.11	61.64	1.
28	10.94	11.92	76.02	177.81	93.11	61.64	1.
29	10.94	11.92	76.02	177.81	93.11	61.64	1.
30	10.94	11.92	76.02	177.81	93.11	61.64	1.
31	10.94	11.92	76.02	177.81	93.11	61.64	1.
32	10.94	11.92	76.02	177.81	93.11	61.64	1.
33	10.94	11.92	76.02	177.81	93.11	61.64	1.
34	10.94	11.92	76.02	177.81	93.11	61.64	1.
35	10.94	11.92	76.02	177.81	93.11	61.64	1.
36	10.94	11.92	76.02	177.81	93.11	61.64	1.
37	10.94	11.92	76.02	177.81	93.11	61.64	1.
38	10.94	11.92	76.02	177.81	93.11	61.64	1.
39	10.94	11.92	76.02	177.81	93.11	61.64	1.
40	10.94	11.92	76.02	177.81	93.11	61.64	1.
41	10.94	11.92	76.02	177.81	93.11	61.64	1.
42	10.94	11.92	76.02	177.81	93.11	61.64	1.
43	10.94	11.92	76.02	177.81	93.11	61.64	1.
44	10.94	11.92	76.02	177.81	93.11	61.64	1.
45	10.94	11.92	76.02	177.81	93.11	61.64	1.
46	10.94	11.92	76.02	177.81	93.11	61.64	1.
47	10.94	11.92	76.02	177.81	93.11	61.64	1.
48	10.94	11.92	76.02	177.81	93.11	61.64	1.
49	10.94	11.92	76.02	177.81	93.11	61.64	1.
50	10.94	11.92	76.02	177.81	93.11	61.64	1.
51	10.94	11.92	76.02	177.81	93.11	61.64	1.
52	10.94	11.92	76.02	177.81	93.11	61.64	1.



56









58





























# APPENDIX C

## SUMMARY OF DAILY STATISTICS OF NARF (AIRFRAME)

DATA FOR JULIAN DATES 1001 TO 2334

TOTAL NUMBER OF OBSERVATIONS = UNKNOWN

DAY	JUL DATE	NORM	DIR LH	DIR L\$	DIR M\$	OVHD\$	P\$	I
298	1001	7008	7338	46058	16598	322	667	72
299	1002	7008	7338	46058	16598	322	667	72
300	1003	7008	7338	46058	16598	322	667	72
301	1004	7284	7666	47954	17749	461	707	75
302	1005	7397	7766	48760	17749	461	716	76
303	1006	7479	7847	49271	17998	469	720	77
304	1007	7642	8095	50872	18501	489	734	79
305	1008	7642	8073	50752	18401	488	731	79
306	1009	7642	8073	50752	18401	488	731	79
307	1010	7642	8073	50752	18401	488	731	79
308	1011	7886	8322	52350	19551	504	744	81
309	1012	7886	8322	52350	19551	504	744	81
310	1013	8062	8503	53200	20046	515	757	83
311	1014	8162	8594	54106	20376	522	762	84
312	1015	8134	8594	54106	20376	522	762	84
313	1016	8134	8594	54106	20376	522	762	84
314	1017	8134	8594	54106	20376	522	762	84
315	1018	8134	8594	54106	20376	522	762	84
316	1019	8134	8594	54106	20376	522	762	84
317	1020	8134	8594	54106	20376	522	762	84
318	1021	8134	8594	54106	20376	522	762	84
319	1022	8134	8594	54106	20376	522	762	84
320	1023	8134	8594	54106	20376	522	762	84
321	1024	8134	8594	54106	20376	522	762	84
322	1025	8134	8594	54106	20376	522	762	84
323	1026	8134	8594	54106	20376	522	762	84
324	1027	8134	8594	54106	20376	522	762	84
325	1028	8134	8594	54106	20376	522	762	84
326	1029	8134	8594	54106	20376	522	762	84
327	1030	8134	8594	54106	20376	522	762	84
328	1031	8134	8594	54106	20376	522	762	84
329	1032	8134	8594	54106	20376	522	762	84











































































# APPENDIX D

## COBB DOUGLAS PREDICTION INTERVAL PROGRAM

```

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C THIS PROGRAM COMPUTES PREDICTION INTERVALS FOR CD MODELS
C ( ENGINE PROGRAM )
C ( FOR AIRFRAMES CHANGE READ FORMAT )
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C IMPLICIT REAL*8(C)
C DIMENSION X(600,4),XT(4,600),XXI(4,4),L(4),Y(4),M(4),D(600,7),
C 1WT(1,4),W(4,1),CXI(4,4),ACOST(600)
C
C INITIALIZE FLAG TO INDICATE (X^X)-1 IS NEGATIVE
C
C ISIG=0
C
C INITIALIZE PARAMETERS
C
C NUM= TOTAL # OF OBSERVATIONS
C NUM1= OBSERVATIONS THE MODEL WAS ESTIMATED FROM
C NUM2= OBSERVATIONS PREDICTION INTERVALS TO BE CMPTD ON
C
C NUM=400
C NUM1=300
C NUM2=100
C A=3.046
C B1=.877
C B2=.401
C B3=.032
C S=.035
C T05=1.65
C DO 10 I=1,NUM
C READ(5,900) (D(I,J),J=1,7)
C ACOST(I)=D(I,3)+D(I,4)+D(I,6)
C 10 CCNTINUE
C 900 FORMAT(9X,F7.2,1X,F7.2,1X,F8.2,1X,F8.2,1X,F7.2,1X,F4.0)
C
C THE FORMAT IS 1 NORM DLH DL$ M$ 4 5 CVHD$ P$ 6 7 I
C
C CCNSTRUCT X MATRIX
C

```



```

C
DO 20 I=1, NUM
X(I,1)=1.0
X(I,2)=ALOG(D(I,1))
X(I,3)=ALOG(D(I,3)/D(I,2))
X(I,4)=ALOG(D(I,6)/D(I,7))
CONTINUE
20 NUM=NUM+1
DC 30 I=NUMP,600
X(I,1)=0.
X(I,2)=0.
X(I,3)=0.
X(I,4)=0.
CONTINUE
30
OBTAIN X*
CALL GMTRA(X,XT,600,4)
OBTAIN X*X
CALL GMPRD(XT,X,XXI,4,600,4)
OBTAIN (X*X)-1 IN DOUBLE PRECISION
DC 32 I=1,4
DC 31 J=1,4
CXI(I,J)=DBLE(XXI(I,J))
CONTINUE
31 CONTINUE
32 CALL DMINV(CXI,4,CT,L,M)
DC 34 I=1,4
DC 33 J=1,4
XXI(I,J)=SGL(CXI(I,J))
CONTINUE
33 CONTINUE
34 DC 35 I=1,4
WRITE(6,902) (XXI(I,J),J=1,4)
CONTINUE
35
902 FORMAT(10,4E20.4)
CCOMPUTE PREDICTED LN(C) IN D(I,7)
CC
DO 40 I=NUMP,NUM
X(I,1)=1.0
X(I,2)=ALOG(D(I,1))
X(I,3)=ALOG(D(I,3)/D(I,2))
X(I,4)=ALOG(D(I,6)/D(I,7))

```



```

40 D(I,7)=A+B1*X(I,2)+B2*X(I,3)+B3*X(I,4)
   CONTINUE
C
C INITIALIZE COUNT FOR PLOT OF COST VS. TIME
C
C ICCUNT=0
C
C COMPUTE H
C
DO 60 I=NUMP,NUM
DO 56 K=1,4
C=0.0
DO 55 J=1,4
Q=Q+XXI(J,K)*X(I,J)
CONTINUE
55 WT(1,K)=Q
56 CONTINUE
V=X(I,1)*WT(1,1)+X(I,2)*WT(1,2)+X(I,3)*WT(1,3)+X(I,4)*WT(1,4)
IF(V.GE.0.0) GO TO 57
ISIG=1
WRITE(6,904) I,V
904 FORMAT(' ',I4,' ',V FOR ' ',I4,' ' IS ' ',E15.7)
GO TO 60
C
C COMPUTE PREDICTION INTERVAL IN LCG FORM
C
57 D(I,4)=S*SQRT(1.0+V)*T05
D(I,1)=D(I,7)-D(I,4)
D(I,2)=D(I,7)+D(I,4)
D(I,5)=EXP(D(I,7))
D(I,7)=ACOST(I)
C
C COMPUTE UPPER AND LOWER INTERVALS IN DOLLARS
C
D(I,1)=EXP(D(I,1))
D(I,2)=EXP(D(I,2))
D(I,3)=EXP(X(I,3))
X(I,3)=EXP(X(I,4))
D(I,3)=D(I,7)-D(I,1)
D(I,4)=D(I,7)+D(I,1)
D(I,7)=D(I,7)-D(I,1)
WRITE(6,901) D(I,7),D(I,2),D(I,3),D(I,4),X(I,2),I
IF(D(I,1).GT.D(I,7)) GO TO 59
IF(D(I,2).LT.D(I,7)) GO TO 59
GO TO 60
59 ICCUNT=ICCUNT+1
60 CONTINUE
901 FCRMAT(' ',3E15.5,10X,2E15.5,' ',N = ' ',E10.5,5X,I4)

```



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FILL UNUSED VECTORS WITH DUMMY VALUES FOR PLOT SCALING PURPOSES

```

DC 80 I=1,NUM1
X(I,2)=1600.
X(I,3)=6.0
X(I,4)=46.000
D(I,1)=30000.
D(I,2)=D(I,1)
D(I,7)=D(I,1)
D(I,5)=D(I,1)
CONJUG=1
IF(I,ISIG,920) GO TO 90
WRITE(6,920) NUM2
14, PREDICTION INTERVALS FOR CCST VS. NORM FOR ,
CALL PLOTP(X(1,2),D(1,2),NUM,1)
CALL PLOTP(X(1,2),D(1,7),NUM,2)
CALL PLOTP(X(1,2),D(1,1),NUM,3)
WRITE(6,921) NUM2
921 FORMAT(1,90) PREDICTION INTERVALS FOR CCST VS. PL FOR ,14,
2, CBSERVATIONS,
CALL PLOTP(X(1,3),D(1,2),NUM,1)
CALL PLOTP(X(1,3),D(1,7),NUM,2)
CALL PLOTP(X(1,3),D(1,1),NUM,3)
WRITE(6,922) NUM2
922 FORMAT(1,90) PREDICTION INTERVALS FOR CCST VS. PI FOR ,14,
3, OBSERVATIONS,
CALL PLOTP(X(1,4),D(1,2),NUM,1)
CALL PLOTP(X(1,4),D(1,7),NUM,2)
CALL PLOTP(X(1,4),D(1,1),NUM,3)
WRITE(6,923) NUM2
923 FORMAT(1,90) PREDICTION INTERVAL FOR ACT. COST VS. PRED. CCST
4, OBSERVATIONS,
CALL PLOTP(D(1,5),D(1,2),NUM,1)
CALL PLOTP(D(1,5),D(1,7),NUM,2)
CALL PLOTP(D(1,5),D(1,1),NUM,3)
WRITE(6,924) I,COUNT,NUM2
924 FORMAT(1,14, ACTUAL COSTS OF ,14, OBSERVATIONS FELL OUTSIDE
5 THE PRED. INTV.)
90 STOP
END

```





## CES PREDICTION INTERVAL PROGRAM

83



```

C
C
C      CCNSTRUCT X MATRIX
C      DO 20 I=1,NUM1
C      X(I,1)=D(I,1)
C      X(I,2)=(D(I,3)/D(I,2))
C      X(I,3)=(D(I,6)/D(I,7))
C      Z=EXP(BA11+BA12*ALOG(X(I,3)/X(I,2)))
C      C1=EXP(BA11/BA12)+Z*((BA12+1.0)/BA12)
C      C2=EXP(BA11/BA12)+1.0
C      C=ALOG(C1/C2)
C      D(I,5)=EXP(BA21)*X(I,1)**BA22*EXP(BA23*C)
C      X(I,1)=1.0
C      X(I,2)=ALOG(D(I,1))
C      X(I,3)=C
C      CCNTINUE
20  CONTINUE
C      NUMP=NUM1+1
C      DO 30 I=NUMP,600
C      X(I,1)=0.
C      X(I,2)=0.
C      X(I,3)=0.
30  CONTINUE
C      OBTAIN X
C      CALL GMTRA(X,XT,600,3)
C      OBTAIN X*X
C      CALL GMPRD(XT,X,XXI,3,600,3)
C      OBTAIN (X*X)-1 IN DOUBLE PRECISION
C      DC 32 I=1,3
C      DO 31 J=1,3
C      FXI(I,J)=DBLE(XXI(I,J))
31  CONTINUE
32  CONTINUE
C      CALL DMINV(FXI,3,FT,L,M)
C      DO 34 I=1,3
C      DO 33 J=1,3
C      XXI(I,J)=SNGL(FXI(I,J))
33  CONTINUE
34  CONTINUE
C      DC 35 I=1,3
C      WRITE(6,902) (XXI(I,J),J=1,3)
35  CONTINUE
902  FORMAT(' ',3E20.4)
C

```



```

C
C
C      COMPUTE PREDICTED LN(C/PL+PI*Z) IN D(I,5)
DO 40 I=NUMP,NUM
  X(I,1)=D(I,1)
  X(I,2)=(D(I,3)/D(I,2))
  X(I,3)=(D(I,6)/D(I,7))
  Z=EXP(BA11+BA12*ALOG(X(I,3)/X(I,2)))
  C1=EXP(BA11/BA12)*Z**((BA12+1.0)/BA12)
  C2=EXP(BA11/BA12)+1.0
  C=ALOG(C1/C2)
  D(I,5)=EXP(BA21)*X(I,1)**BA22*EXP(BA23*C)
  G(I,1)=X(I,2)+X(I,3)*Z
  D(I,5)=ALOG(D(I,5))
  X(I,1)=1.0
  X(I,2)=ALOG(D(I,1))
  X(I,3)=C
  CONTINUE
40
C
C      INITIALIZE COUNT FOR PLOT OF COST VS. TIME
ICCOUNT=0
C
C      COMPUTE V ( H IN DISCUSSION )
DO 60 I=NUMP,NUM
  DC 56 K=1,3
  Q=0.0
  DC 55 J=1,3
  Q=Q+XXI(J,K)*X(I,J)
  CONTINUE
55 WT(1,K)=Q
56 CONTINUE
  V=X(I,1)*WT(1,1)+X(I,2)*WT(1,2)+X(I,3)*WT(1,3)
  IF(V*GE.0.0) GO TO 57
  ISIG=1
  WRITE(6,904) I,V
  FORMAT(1,40X,' V FOR ',I4,' IS ',E15.7)
904 GC TO 60
C
C      COMPUTE PREDICTION INTERVAL IN LCG FORM
57 D(I,4)=S*SQRT(1.0+V)*T05
  D(I,1)=D(I,5)-D(I,4)
  D(I,2)=D(I,5)+D(I,4)
  D(I,5)=EXP(D(I,5))*G(I)
  D(I,7)=ACOST(I)
C
C      COMPUTE UPPER AND LOWER INTERVALS IN DOLLARS

```



C

```

D(I,1)=EXP(D(I,1))*G(I)
D(I,2)=EXP(D(I,2))*G(I)
X(I,2)=EXP(X(I,2))
X(I,3)=EXP(X(I,3))
D(I,3)=D(I,2)-D(I,1)
D(I,4)=D(I,3)-D(I,1)
WRITE(6,901) D(I,1),D(I,2),D(I,3),D(I,4),X(I,2),I
IF(D(I,1).GT.D(I,7)) GO TO 59
IF(D(I,2).LT.D(I,7)) GO TO 59
GO TO 60
59 ICCOUNT=ICOUNT+1
60 CONTINUE
901 FORMAT(' ',3E15.5,10X,2E15.5,' N = ',E10.5,5X,I4)

C
C
C  FILL UNUSED VECTORS WITH DUMMY VALUES FOR PLOT SCALING PURPOSES

DC 80 I=1,NUM1
X(I,2)=6000.
X(I,3)=1.1
D(I,1)=100000.
D(I,2)=D(I,1)
D(I,7)=D(I,1)
D(I,5)=D(I,1)
CONTINUE
80 IF(ISIG.EQ.1) GO TO 90
WRITE(6,920) NUM2
FORMAT(' ',90% PREDICTION INTERVALS FOR CCST VS. NORM FOR ',
1 I4,' OBSERVATIONS. ')
CALL PLOTP(X(I,2),D(1,2),NUM,1)
CALL PLOTP(X(I,2),D(1,7),NUM,2)
CALL PLOTP(X(I,2),D(1,1),NUM,3)
WRITE(6,921) NUM2
FORMAT(' ',90% PREDICTION INTERVALS FOR CCST VS. D FOR ',I4,
2 ' CBSERVATIONS. ')
CALL PLOTP(X(I,3),D(1,2),NUM,1)
CALL PLOTP(X(I,3),D(1,7),NUM,2)
CALL PLOTP(X(I,3),D(1,1),NUM,3)
WRITE(6,923) NUM2
FORMAT(' ',90% PREDICTION INTERVAL FOR ACT. COST VS. PRED. COST
4 FOR ',I4,' OBSERVATIONS. ')
CALL PLOTP(D(1,5),D(1,2),NUM,1)
CALL PLOTP(D(1,5),D(1,7),NUM,2)
CALL PLOTP(D(1,5),D(1,1),NUM,3)
WRITE(6,924) ICCOUNT,NUM2
FORMAT(' ',I4,' ACTUAL COSTS OF ',I4,' OBSERVATIONS FELL OUTSIDE
5 THE PRED. INTERVAL. ')
90 STOP

```

C  
C  
C





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13. ABSTRACT

The objective of this study was to investigate a proposed method of auditing cost-effectiveness analyses of technological changes. The method is based on the use of cost functions to predict costs of operating with and without the improved technology. A comparison of these predicted costs indicates whether the technological change is cost-effective. Results of the comparison can then be used to audit more detailed analyses of the change. The investigation employed econometric techniques in a case study application of the method to a technological change which occurred at the Naval Air Rework Facility, North Island, San Diego, California.





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